Modified Brokk Demolition Machine with Remote Console

Robotics Crosscutting Program
Deactivation and Decommissioning
Focus Area

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INNOVATIVE TECHNOLOGY
Summary Report

Modified Brokk Demolition Machine with Remote Console

OST/TMS ID 2938

Robotics Crosscutting Program
Deactivation and Decommissioning
Focus Area

Demonstrated at
Idaho National Engineering and
Environmental Laboratory
Idaho Falls, Idaho

Purpose of this document

Innovative Technology Summary Reports (ITSRs) are designed to provide potential users with the information they need to quickly determine if a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from the U.S. Department of Energy's (DOE's) Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. ITSRs are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published ITSRs are available on the OST web site at http://ost.em.doe.gov under "Publications".

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SECTION 1
SUMMARY

Introduction

The U.S. Department of Energy (DOE) continually seeks safer and more cost-effective technologies for use in the deactivation and decommissioning (D&D) of nuclear facilities. The DOE Office of Science and Technology (OST) Robotics Crosscutting Program (Rbx) is a needs-directed program for the development of robotic technologies that hold significant promise to provide faster, safer, or less expensive systems for application to environmental management (EM) problems. The Rbx is structured into product lines that align with major EM problem areas and the associated focus areas, such as the Deactivation and Decommissioning Focus Area (D&DFA). A multi-site team performs the work in each of the Rbx product lines with activities coordinated by a designated lead site. Oak Ridge National Laboratory (ORNL) is the lead site for the Rbx D&D Product Line.

During fiscal year (FY) 1999, the Rbx identified the need for a low-cost D&D system to support selected D&D activities at the Idaho National Engineering and Environmental Laboratory (INEEL) in conjunction with the Compact Remote Console (CRC) being developed under Rbx D&D funding at ORNL. The low-cost D&D system identified for integration with the ORNL CRC was the commercially available Brokk 250. This integrated system, referred to as the Modified Brokk Demolition Machine with Remote Console, was deployed in conjunction with the D&DFA Large-Scale Demonstration and Deployment Project (LSDDP) and the INEEL D&D site operations. This deployment was completed during D&D activities at the INEEL Security Training Facility (STF) in January 2000. This Innovative Technology Summary Report (ITSR) will provide a discussion of the technologies involved in this deployment.

Technology Summary

During FY 1999, the INEEL LSDDP purchased the commercially available Brokk 250 demolition system, which was developed by Holmhed Systems AB in Skelleftea, Sweden. This system was demonstrated at the INEEL during FY 1999 in various D&D activities and has subsequently been transferred to the INEEL D&D operations as part of the general D&D equipment pool. Figure 1 shows an INEEL D&D operator using the off-the-shelf technology in D&D operations at the STF.

Figure 1: The Brokk 250 and a D&D operator in demolition activities.

During FY 2000, the D&D Rbx Product Line Manager directed the INEEL Rbx D&D group to modify this Brokk 250 to allow remote capability from the CRC, which was developed by ORNL. Figure 2 illustrates the modified Brokk 250 and the CRC. This Modified Brokk Demolition Machine with Remote Console was demonstrated and deployed during D&D activities at the INEEL STF in January 2000.

Figure 2: INEEL Modified Brokk 250 and the ORNL CRC.

Demonstration Summary

During FY 1999, the Rbx identified the need for a low-cost D&D system to support selected D&D activities at the INEEL in conjunction with the CRC, which was developed under Rbx D&D funding at ORNL. The low-cost D&D system identified for integration with the ORNL CRC was the commercially available Brokk 250. This integrated system, referred to as the Modified Brokk Demolition Machine with Remote Console, was deployed during D&D activities at the INEEL STF in January 2000. Specifically, the system was used by an operator to remotely remove, size-reduce, and stage overhead piping and facility equipment located in the basement of the STF. Prior to using the Modified Brokk Demolition Machine with Remote Console, this work was being done with the operator in the area in direct line-of-sight of the operation.

Key Results

The benefits from this Modified Brokk Demolition Machine with Remote Console include:

- operable by remote control, allowing the operator to be positioned at a safe distance from high radiation areas, falling debris, cold and hot temperatures, and other environmental concerns;
- ability to do work in out-of-sight conditions using image-stabilized cameras;
- working time less than half that of most manual tools, significantly reducing cost, schedule, and worker radiation exposure;
- powered by a 480-V ac, 3-phase motor, eliminating problems of exhaust fumes in containment areas;
- useful for a wide range of tasks in various work conditions from breaking, removing, and loading concrete debris to removing radioactive waste from high radiation areas; and
- durable––operated on double 10-hour shifts for weeks without failure (expected useful life is about 10 years).

Contacts

Technical

Matthew O. Anderson, Rbx D&D Technology Lead, Idaho National Engineering and Environmental Laboratory, (208) 526-4308, matthew@inel.gov

Mark Noakes, Rbx D&D Technology Lead, Oak Ridge National Laboratory, (865) 574-5695, noakesmw@ornl.gov

Thomas N. Thiel, D&D Operations Project Lead, Idaho National Engineering and Environmental Laboratory, (208) 526-9876, tnt@inel.gov

Thomas E. Bechtold, Waste Management Technologies, Idaho National Engineering and Environmental Laboratory, (208) 526-7738, bechte@inel.gov

Bill Barraugh, Brokk Sales Representative, North American Sales, Inc., (360) 794-1277, http://www.nasbrokk.com

Management

Dennis Haley, Rbx D&DFA Product Line Manager, Oak Ridge National Laboratory, (865) 576-3965, haleydc@ornl.gov

Harold Shoemaker, National Energy Technology Laboratory, (304) 285-4715, hshoem@netl.doe.gov

Steve Bossart, Project Manager, U.S. Department of Energy, National Energy Technology Laboratory, (304) 285-4643, steven.bossart@netl.doe.gov

Chelsea Hubbard, U.S. Department of Energy, Idaho Operations Office, (208) 526-0645, hubbarcd@inel.gov

Ronald A. Lujan, Robotics Manager, Idaho National Engineering and Environmental Laboratory, (208) 526-4045,ronl@inel.gov

Bradley J. Frazee, D&D Operations Manager, Idaho National Engineering and Environmental Laboratory, (208) 526-3775, bjf@inel.gov

Richard H. Meservey, LSDDP Project Manager, Idaho National Engineering and Environmental Laboratory, (208) 526-1834, rhm@inel.gov

Web Site

The INEEL Robotics Internet web site address is:
http://www.inel.gov/capabilities/robotics/index.html
The INEEL TDC Technology Catalog record is available at web site address:
http://techcatalog.inel.gov/searchreportresults.asp?id=164

Other

All published ITSRs are available on the OST web site at http://ost.em.doe.gov under “Publications”. The Technology Management System (TMS), also available through the OST web site, provides information about OST programs, technologies, and problems. The OST TMS ID for the Modified Brokk Demolition Machine with Remote Console is 2938.

Section 2
TECHNOLOGY DESCRIPTION

Overall Process Definition

Demonstration Goals and Objectives

The DOE continually seeks safer and more cost-effective technologies for use in deactivation and decommissioning of nuclear facilities. The DOE OST Rbx is a needs-directed program for the development of robotic technologies that hold significant promise to provide faster, safer, or less expensive systems for application to EM problems. Through developing innovative technologies that meet these goals and evaluating them in-field with baseline technologies, the OST is able to quantify and document the benefits that can be realized from a side by side comparison of the innovative and baseline technologies. This direct comparison provides an opportunity to assess the impact of the innovative technology against the baseline and validate the benefits to be gained.

This field demonstration is in support of these developmental activities and objectives. During FY 1999, the Rbx identified the need for a low-cost D&D system to support selected D&D activities at the INEEL in conjunction with the CRC, which was developed under Rbx D&D funding at ORNL. The low-cost D&D system identified for integration with the ORNL CRC was the commercially available Brokk 250. The integrated system is referred to as the Modified Brokk Demolition Machine with Remote Console. The goal of the field demonstration was to determine if adequate visual cues and remote controllability could be given to an equipment operator to allow D&D activities to proceed as efficiently from a remote site as in-field line-of-sight operations.

Description of the Technology

During 1997–1998 a Brokk 250 was purchased by the INEEL LSDDP for a comparison of performing manual versus remote D&D activities, such as concrete sizing and removal. The Brokk family of demolition equipment is manufactured by Holmhed Systems AB of Sweden and uses a teleoperated, articulated, hydraulic boom with various tool-head attachments. The Brokk 250 consists of a revolving table, capable of continuous rotation, mounted on a tractor-like base. Solid rubber wheels mobilize the equipment, and hydraulic outriggers extend beyond the tires to add stability during operation. The unit requires a 480-V ac, 50-A circuit for its power source. Someone can operate the Brokk from 400 ft away using either a tethered portable controller or a wireless radio frequency (rf) portable controller. In the baseline mode, the Brokk is controlled by an operator standing in relatively close proximity of the machine with line-of-sight vision of the work site. Figure 3 shows the Brokk BM 250 being used for D&D activities while using the wireless rf controller.

Figure 3: The Brokk 250 and a D&D operator in demolition activities.

Following are some of the physical characteristics of the Brokk 250.

- Weight: 6,750 lb. without attachments
- Minimum Height: 142 in.
- Minimum Width: 59 in.
- Minimum Length: 47 in.
- Operating width: 97 in.
- Maximum Attachment Weight: 660 lb.
- Hydraulic breaker energy per blow: 1,000 ft-lb.

Various tool head attachments are available for this system including a hydraulic hammer, an excavating bucket, a concrete crusher, and a La Bounty Shear, which is shown attached in Figure 3. The La Bounty Shear was the primary tool head used for this demonstration and is capable of cutting rebar, pipe, and other metal and weighs approximately 600 lb. A field demonstration of a Brokk BM 150 was conducted in 1997-1998 at the Chicago-Pile No. 5 Research Reactor Large-Scale Demonstration Project. An ITSR, "Remote-Controlled Concrete Demolition System", was written in April 1998 detailing the use of the Brokk 150 versus jackhammers for concrete removal.

In order to perform D&D activities from a truly remote non-line-of-sight location, the Brokk 250 was retrofitted with two image-stabilized cameras mounted in a pan-and-tilt aluminum enclosure. The image-stabilized DRaySEE™ camera system is commercially available from RVision, Inc., and produces 350 lines NTSC video, pans 360°, tilts 110°, and provides 24 times image magnification (12X optical). The 12-V dc system requires separate power for the pan-and-tilt functions and a serial interface to control camera zoom features. These two cameras were mounted on two actuated arms, which are located on the Brokk 250's cover, as shown in Figure 4. The actuated arm system allows the cameras to be positioned in the optimal viewing position during work activities and to be retracted while the Brokk is being moved throughout the remote area. By mounting the camera and actuator system on the cover, the Brokk 250 can easily be changed from remote-camera ready to original equipment by simply interchanging covers.

Figure 4: The Brokk 250 with cameras and actuated arms deployed.

An auxiliary camera system was developed, which can be placed anywhere in the facility, and which can be used for remotely viewing work activities from a different perspective. This system was developed using a third DRaySEE™ camera system, which was mounted on a 5-ft pole and enclosure. Located in the enclosure are rechargeable batteries, a battery recharging system, and electronics, which allow rf or hard-wired video transmission. Figure 5 illustrates the facility camera and the electronics enclosure.

Figure 5: The Facility Camera with its electronics enclosure.

To minimize the number of tethers required to interface to the Brokk and facility camera system, an rf RS-485 multi-drop to RS-232 serial interface was developed. This system was engineered using Opto-22 smart modules, which communicate using a multi-drop RS-485 interface and a proprietary addressing protocol. The use of these smart modules allowed a single serial interface to control the zoom features of each camera, activate the digital-to-analog control on each camera's pan-and-tilt, and activate the digital-to-analog control on the camera positioning arms. Modules needing to be added to the RS-485 interface located in the facility camera enclosure, required an rf RS-485 radio. All system control and video feeds were routed to an enclosure at the rear of the Brokk for conversion to fiber-optic communications. A single multi-mode multi-fiber tether was connected from this enclosure on the Brokk to the CRC, which can be located up to 1.5 miles away. Also, a simple conversion circuit was designed to allow the rf portable Brokk controller to be mounted in the Compact Remote Console and interface to this fiber-optic tether. Figure 6 shows the various enclosures required for remote camera viewing and control for the fiber-optic-tethered Modified Brokk Demolition Machine.

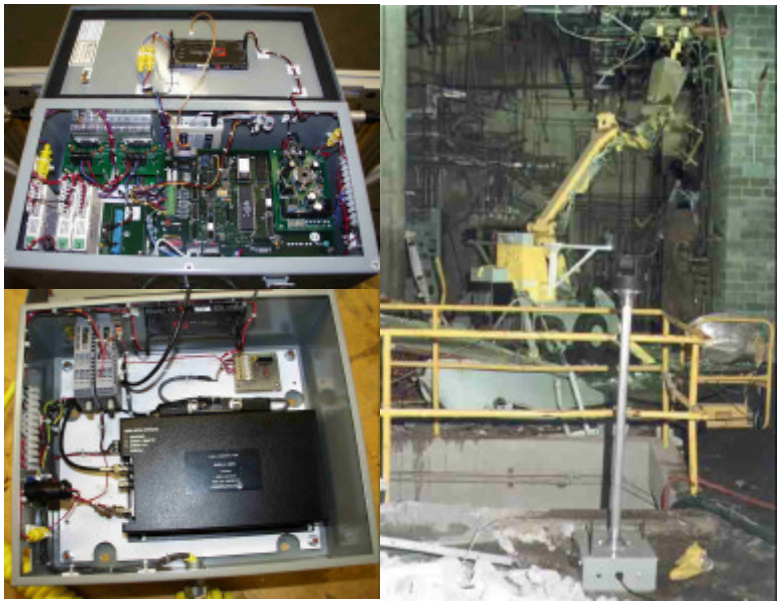

Figure 6: Electronics enclosures and the Modified Brokk 250 with enclosures mounted.

The purpose of the CRC is to condense a typical multi-monitor, multi-rack large operator control console into a single, easy-to-relocate ergonomic station. The CRC measures 30 in. wide by 61 in. long and 76 in. tall and consists of a 4-panel video array, which is mounted on a mast in front of an ergonomic chair. These are subsequently mounted on a base, which serves as an enclosure for associated power, video switchers, and control and fiber-optic electronics. Also mounted on a swivel arm on the CRC is a control computer with a touch-screen, which serves as an intuitive graphical user interface (GUI) to the Modified Brokk Demolition Machine. Figure 7 shows the CRC with an integrated portable Brokk 250 controller and an inside view of the base enclosure. For an in-depth, detailed discussion of the CRC, see ITSR OST/TMS ID 2180, “Compact Remote Operator Console”, August 2000.

Figure 7: The CRC and inside its base enclosure.

System Operation

For this demonstration, qualified INEEL D&D Brokk equipment operators were used to remotely operate the Modified Brokk Demolition Machine using the CRC. Each of these operators had received model-specific Brokk operator training from the manufacturer and had had significant operating time in the field. The original Brokk controller was integrated into the CRC, therefore eliminating the need for additional training on Brokk-specific operations. The GUI, provided on the CRC control computer, required a short, half-hour training session for the operators. This training session included an explanation on how to control the camera and actuator systems on the modified Brokk and how to setup the 4-panel video array according to each operator's personal preference.

Two operators were required for safe field-operation of the Modified Brokk Demolition Machine with the Remote Console, one at the CRC responsible for operating the Brokk and another near the remote location to notify the CRC operator of any unsafe conditions necessitating a stop work. Activities were conducted under INEEL D&D operation's procedures, and personal protective equipment (PPE), such as hard hats, safety glasses, and steel-toed shoes, was used during setup of the remote equipment. Personnel were briefed on the D&D site safety requirements, and all safety guidelines were followed.

Standard 120-V ac power is required for operation of the CRC, and the Brokk machine requires 480-V ac from a facility or a generator. The camera, motor, and electronic systems associated with modifying the Brokk machine get their power from the Brokk platform directly, so no additional power systems are required.

Table 1 summarizes the operational parameters and conditions of the Modified Brokk Demolition Machine with Remote Console demonstrated at the INEEL STF in January 2000.

Table 1. Operational parameters and conditions of the Modified Brokk Demolition Machine with Remote Console Demonstration

Work area location	INEEL STF, Scoville / Idaho Falls, ID
Work area access	INEEL D&D operations restrictions to equipment operational areas and D&D site.
Work area description	Work area restricted and controlled due to noise and safety requirements, requiring training, hard hat, safety glasses, and safety shoes for entry. Actual operation conducted in a trailer eliminating the need for PPE at the CRC.
Work area hazards	Noise hazards Tripping hazards Water hazards Heavy equipment operations High-voltage hazards
Equipment configuration	CRC located in trailer and attached to the Modified Brokk located at remote D&D site 600 ft away
Work crew	Minimum work crew: • 1 Brokk operator • 1 D&D site operator • 2 Robotics personnel for system setup
Additional support personnel	• 1 Health and Safety Observer (periodic)
Special skills/training	Site mandated Brokk specific training. Review and briefing of D&D site safety operations and sign-in. CRC specific training. Skill was required to operate Brokk and associated remote camera equipment. Modified Brokk System training, skill, and experience are required for setup and operation.

Primary waste generated	No primary waste was generated beyond normal D&D operations.
Secondary waste generated	No secondary waste was generated.
Waste containment and disposal	N/A
Technology design purpose	Equipment is designed to perform D&D demolition operations from a remote location.
Portability	Modified Brokk camera equipment and CRC can be packaged and transported to D&D site easily. Brokk machine requires trailer for transporting to D&D site.
Work area preparation	No facility preparation was necessary for the demonstration.
PPE	Steel-toed shoes, safety glasses, leather gloves, hard hats
Power, fuel, etc.	Diesel fuel for remote generator Facility power used for CRC

SECTION 3
PERFORMANCE

Demonstration Plan

Problem Addressed

Many DOE facilities have fulfilled their useful lives and are in the process of being deactivated and decommissioned. Tasks associated with D&D include piping, conduit, and concrete sizing and removal; interior walls pulverized and removed; large enclosures sized and removed; office areas, stairs, and walk ways removed; and so forth. D&D in the nuclear industry often occurs in facilities that have been used for nuclear experiments or fuel reprocessing and storage. These facilities frequently become radiologically contaminated and require equipment that can be controlled from a remote environment, which allow operators to perform the necessary D&D tasks safely. It is for this purpose that the Rbx directed ORNL and INEEL to develop the low-cost D&D system (now known as the Modified Brokk Demolition Machine), which can be remotely operated from the CRC.

Demonstration site description

The INEEL site occupies 569,135 acres (889 square miles) in southeast Idaho. The site consists of several primary facility areas situated on an expanse of otherwise undeveloped, high-desert terrain. Buildings and structures at the INEEL are clustered within these primary facility areas, which are typically less than a few square miles in size and separated from each other by miles of primarily undeveloped land.

As the INEEL and ORNL Rbx D&D team developed the Modified Brokk Demolition Machine integrated with the CRC, they determined that a field test was necessary to adequately qualify and quantify the capability of the remote system. The INEEL D&D site operation's Brokk 250 was being used for D&D of the STF, which is located at the Central Facilities Area at the INEEL site. The STF was originally designed and built as the Experimental Organic Cooled Reactor Facility that was never put into service. As such, the facility contains many of the nuclear systems normally contained in radiologically contaminated facilities requiring D&D but without the risks and hazards associated with contaminated facilities. This resulted in a perfect test bed for the Modified Brokk Demolition Machine with Remote Console. D&D site operations were already using the Brokk 250 to remove and size piping, walkways, control panels, and large metal storage boxes from the basement of the STF. These D&D tasks were being performed in the cold temperatures of the Idaho winter with the operators dressed in adequate clothing and PPE as required by D&D operations. The Brokk 250 rf controller was being used to allow local operations. A request was made by the Rbx D&D team to the STF D&D foreman asking for a portion of the STF basement to be reserved for testing of the various systems developed for remote operation of the Brokk 250. The request was granted, and an initial field test was scheduled for January 18, 2000.

Major objectives of the demonstration

The first objective of the Rbx D&D group is to identify existing technologies, either unproven or requiring improvement in D&D applications, that address the defined problems or needs of DOE D&D activities. The second objective is to develop innovative technologies that improve upon the existing technologies or create a new capability. Finally, these innovative technologies are tested to quantify and document the benefits that can be realized from a side-by-side comparison of the innovative and baseline technologies. Possible benefits include reduced cost, reduced exposure, increased safety, reduced schedule, and ease of application. This direct comparison provides an opportunity to assess the impact of the innovative technology against the baseline and to validate the benefits to be gained.

In keeping with these objectives, the original purpose of testing the Modified Brokk Demolition Machine with Remote Console was to determine if adequate visual cues and remote controllability could be given to an equipment operator to allow D&D activities to proceed as efficiently from a remote site as in in-field line-of-sight operations. Also, the sooner the system was in the field and performing real D&D tasks with existing D&D equipment operators, the sooner the system would be accepted and used for other D&D jobs slated for the INEEL in radiologically contaminated areas. No test plan was put into place before locating the equipment at the STF. As stated, the objective was to determine and compare the adequacy of the system to perform D&D tasks that were being performed line-of-sight in the hazardous environment and receive feedback from the users to determine ways the system might be improved.

Major elements of the demonstration

This demonstration provided field data regarding remote non-line-of-sight D&D operations versus in the environment local D&D operations. D&D tasks evaluated included:

- difficulty of setting up the remote equipment;
- remotely positioning the Modified Brokk Demolition Machine using the CRC;
- sizing, removing, and staging conduit and piping;
- removal and staging of large control panels; and
- removal and staging of a large stainless-steel storage box.

Results

The Modified Brokk Demolition Machine with Remote Console worked very well over a period of 5 days. On the morning of the first day, the equipment was loaded into a trailer and transported from the Robotics Laboratory, which is located in Idaho Falls, Idaho, to the STF, which is located 50 miles west of Idaho Falls at the Central Facilities Area. The Brokk 250 was already located in the basement of the STF and attached to the associated power generator. The Brokk 250 was de-energized, and the cover was removed for replacement with the cover retrofitted with the remote camera and actuator equipment. The 1/4-in. diameter fiber-optic tether was run from the STF basement to the control trailer, which was located ~ 600 feet away and attached to the CRC. The control trailer was used to limit access during operations, and it provided a heated, safer environment for the operator to work than in the basement of the STF. The entire setup of the Modified Brokk Demolition Machine with Remote Console, including the initial half-hour control console training and pre-job briefing, required ~ 3.5 hours.

The equipment operator previously operating the Brokk 250 in the basement of the STF was relocated in the control trailer at the CRC. Figure 8 shows this operator using the Brokk controller integrated into the CRC to operate the Modified Brokk Demolition Machine in the basement of the STF. The tasks listed above were initiated during the first 2 days at the STF D&D site. At first, the operator found it unusual operating the Brokk system without hearing the system as there was no audio feedback from the remote environment. As the 2-day field trial progressed, the operator became nearly as efficient at performing the listed D&D tasks remotely as while in the field. The rate at which the listed tasks were being accomplished while in the field was nearly matched. The operator was pleasantly surprised at the ease of viewing the overall environment from the facility camera and the unwavering view from the image-stabilized cameras mounted on the Brokk machine.

Figure 8: The D&D Operator at the CRC and the Modified Brokk in D&D activities.

At the conclusion of the 2-day field trial, operator feedback was obtained to determine the strengths and weaknesses of the system. At the request of the D&D site operations and with the permission of the Rbx D&D Product Line Manager, the Modified Brokk Demolition Machine was left for an additional 3 days to allow the remaining listed D&D tasks to be completed from the remote control station. The operators were so pleased with the system and found that it impacted the schedule less than anticipated that they preferred the ease and comfort from the CRC to the cold wet basement of the STF. Additionally, a media event with local news stations was conducted at the end of the 5 days to present the capabilities of the new Modified Brokk Demolition Machine with Remote Console operating in the field at the STF.

The demonstration collected valid operational data so that legitimate comparison can be made between the innovative technology and the baseline technology in the following areas:

- safety,
- productivity rates,
- ease of use,
- limitations and benefits, and
- cost.

SECTION 4
TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Competing Technologies

Baseline technology

A number of technologies are available for performing the listed D&D tasks evaluated under this innovative technology demonstration. Some of these technologies include:

- teleoperated Brokk demolition equipment (baseline technology);
- manual jackhammer, cutters, and saws;
- backhoe mounted equipment;
- robotics with various tool attachments; and
- explosives.

The teleoperated Brokk 250 provides the increased capability over the manual and heavy equipment systems of moving the operator out of harms way; the ability to work in small areas; documented reduction in cost, schedule, and worker exposure; and a wide range of tasks in various work conditions. The Modified Brokk Demolition Machine with Remote Console adds to these benefits the ability to remotely operate existing equipment from an increased safety zone in hazardous environments or increased remote capability in the case where hands-on, line-of-sight work is prohibitive because of constraints, such as radiological contamination. The benefits of the Modified Brokk Demolition Machine with Remote Console are:

- operated by remote control, allowing the operator to be positioned at a safe distance from high radiation areas, falling debris, and other environmental concerns;
- ability to do work in out-of-sight conditions;
- working time is less than half that of most manual tools, significantly reducing cost, schedule, and worker radiation exposure;
- powered by a 480-V ac, 3-phase motor, eliminating problems of exhaust fumes in containment areas; and
- useful for a wide range of tasks in various work conditions from breaking, removing, and loading concrete debris to removing radioactive waste from high radiation areas.

Technology Applicability

Any site requiring D&D operations with the constraints of complete remote operation (hands-off non-line-of-sight) would benefit from the use of the Modified Brokk Demolition Machine with Remote Console. For example, two different facilities at the INEEL site are slated for D&D during the next few years. As the Brokk 250 has become a general piece of equipment for the INEEL D&D site operations, it is currently scheduled to be used in these D&D projects for concrete, piping, conduit, and flooring removal. Additionally, there is the need to D&D two test reactors in these facilities, and the Brokk 250 will be used

for this work. The radiation fields expected during this job prohibit manual operations anywhere near the area, and the Modified Brokk with the CRC, therefore, is currently needed to complete this job. This is just one example of D&D operations that could benefit from the use of this technology.

Patents/Commercialization/Sponsor

The development of this technology was sponsored by the D&DFA and performed by the OST (EM-50) Rbx. The engineering documentation associated with creating the Modified Brokk Demolition Machine is available from the INEEL. The engineering documentation for the CRC is available from the ORNL. The Brokk 250 and associated tools are commercially available from Brokk North American Sales, Inc.

SECTION 5
COST

Methodology

This section compares the cost associated with D&D activities using the baseline technologies versus the innovative technologies. For this cost analysis the baseline technology will consist of a commercially available Brokk 250 and a La Bounty Shear. The cost for this technology is obtained via the INEEL LSDDP from an August 1999 comparison of the Brokk 250 to manual D&D operations. The labor rates for the INEEL-furnished crewmembers and equipment are based on standard rates for the INEEL site. The details of this 1999 analysis are provided in Appendix B. Developing a cost comparison associated with the Modified Brokk Demolition Machine with Remote Console is problematic at best. As the original purpose of the January demonstration was to determine field readiness of the robotic system and to gain exposure for the increased capability for the Brokk 250, no test-plan nor cost-analysis personnel were obtained to collect cost data on the system. A discussion of system duplication costs and associated system operation will at least be provided.

Cost Analysis

Per the LSDDP cost analysis and Rbx engineering data, Table 2 summarizes the initial capital outlay for the Modified Brokk Demolition Machine with Remote Console.

Table 2. Innovative Technology Acquisition Costs

Acquisition Option	Item Description	Cost
Equipment purchase	Brokk 250	$105,000
	Radio controller	$7,500
	Cabling	$900
	La Bounty Shear	$18,000
Equipment development	Modified Brokk Demolition Machine w/ facility camera	$70,000
	CRC	$50,000

The LSDDP cost analysis of Appendix B compares the cost of removing piping from walls using the Brokk 250 versus manual labor. The analysis concludes that a Brokk 250 with a crew of 2 people for 4 days can perform the same work it would require 4 people for 40 days. The use of the Brokk 250 has the advantage of increased worker safety because personnel are not in the area of falling pipes and the elimination of setting up and using scaffolding. The LSDDP analysis concludes that it costs $8,560 to perform a job that manually costs $75,446 for a savings of $66,886.

Table 3 summarizes the costs associated with the Modified Brokk Demolition Machine with Remote Console demonstration in January.

Table 3. Costs associated with Modified Brokk Demolition Machine Demonstration

Description	Labor	Cost
Location of vehicle @ STF and set-up	.5 man-days @ $500/man-day = $250	$250
First 2-day field trial	4 man-days @ $500/man-day = $2,000	$2,000
3-day field deployment	6 man-days @ $500/man-day = $3,000	$3,000
	Total costs	$5,250

Additional costs associated with this system would be the rental or purchase of a power generator and an anticipated $10/hour maintenance cost. INEEL D&D operations already had the power generator and system maintenance in place for this demonstration.

It should be noted that this work was performed in a facility that was not radiologically contaminated. When the deployment of this equipment takes place in a truly hazardous environment wherein this equipment was designed to perform, then a cost comparison including radiation control technicians and radiation trained personnel with PPE will need to be considered and documented.

Cost Conclusions

The operator efficiency using the Modified Brokk Demolition Machine with Remote Console was initially documented as being lower than that of the baseline line-of-sight system. However, by the end of the 2-day field trial, the operator reported being able to perform operations remotely at nearly the same rate as being in the field. One conclusion that can be drawn from this cost comparison is that potentially production rates could reach the same level in remote operation as in non-remote operation while providing a safer operator environment. Therefore, after the initial capital outlay for the remote demolition equipment, no additional cost or loss in productivity would be incurred. Also, a previously documented significant cost savings definitely exists for either remote or line-of-sight operations versus manual D&D operations (see Appendix B).

SECTION 6
REGULATORY AND POLICY ISSUES

Regulatory Considerations

There are no known regulations associated with the use of the Modified Brokk Demolition Machine with Remote Console. Its use at the INEEL STF D&D site was covered under the INEEL D&D site operations and safety procedures.

Safety, Risks, Benefits, and Community Reaction

The Modified Brokk Demolition Machine with Remote Console is designed to be as safe to use as the baseline system. The only additional risk resulting from the innovative technology over the baseline technology is the difficulty associated with remotely driving the equipment over long distances. This risk is mitigated by design features and procedural requirements such as:

- cameras located on the Brokk 250 cover are placed on actuators to allow a minimal operating envelope as close to the original Brokk 250 as is possible,
- an additional facility camera was developed for overview of remote operations to alert the operator to possible hazards in the area, and
- an operator was located near enough to the operating area to notify the remote operator of unsafe or unusual conditions necessitating work to be stopped.

There are no adverse safety or socioeconomic impacts on the community. As discussed previously, a media event was held at the conclusion of this demonstration, and the technology was very well reported and received by the local Idaho residents. Several television stations and local newspapers carried the report on the innovative technology being used to improve productivity and safety conditions at the INEEL. The news reports included an interview with the INEEL D&D operations STF project manager, the Brokk 250 operator, and the Rbx D&D technology lead. To date, these reports and publications have consisted of only positive responses from the public.

SECTION 7
LESSONS LEARNED

Implementation Considerations

The commercially available Brokk 250 is a mature technology, which performed very well during the INEEL demonstration and has a proven track record during the past 2 years under some very extreme operating conditions with the INEEL D&D operations. The Modified Brokk Demolition Machine with Remote Console also performed well, but some minor improvements have been suggested to enhance operation and effectiveness. These improvements are listed in the Technology Limitations and Needs for Future Development portion of this section.

It should be noted that the Modified Brokk Demolition Machine with Remote Console does require some small measure of skill to operate. Most of the controls associated with the camera, actuator, and CRC are quite intuitive, but it is recommended that operators receive the vendor-provided, model-specific Brokk training and significant field operation time before operating the system remotely through the CRC. It is not absolutely necessary to have a person in the remote environment for tether management or unsafe condition notification, but it was helpful and procedurally required during this demonstration, and it is highly recommended.

Technology Limitations and Needs for Future Development

At the conclusion of the 2-day field trial, the D&D site operations personnel were interviewed for operator feedback on the Modified Brokk Demolition System with Remote Console. Following is a list of their comments including recommendations for improvements.

1. The CRC ergonomic setup is exceptional with adequate chair and monitor adjustments, and mounting of the Brokk controller allows for normal comfortable operations.

2. Operation from a remote trailer is preferred due to improved safety conditions, comfort, operator isolation, and so forth.

3. Visual cues from the Modified Brokk were adequate and intuitive allowing productive operations from the CRC.

4. Audio feedback from the remote environment is a must. In addition to the normal feedback one obtains from sound under remote operations, the operator relies upon the sounds from the hydraulic system to determine when the Brokk has been successfully activated. During the demonstration, a remote operator was used to signal to the Brokk operator when the system was operational, which is not the preferred mode of operation.

5. Optional joystick control of the camera functions would be preferable to just a touch-screen interface. The operators were more familiar with joystick controllers and the need to continuously touch the operator interface touch screen on a specific button to move the cameras proved to be occasionally frustrating. The operators felt a system with the option of joystick or touch screen would be preferred.

6. The facility camera is designed to transmit video via an rf transmitter to the Brokk, where the signal is passed via the fiber-optic tether to the operator. Commercially available rf video transmitters are currently very limited to line-of-sight operations and very susceptible to noise and interference. These limitations plagued the operator with frequent dropouts of the overview picture and caused some significant frustration under these operating conditions. It was suggested that an optional coaxial cable be installed from the facility camera to the Brokk 250 and then passed via the fiber-optic cable to the operator to reduce these video problems.

Either the Modified Brokk camera system or the CRC is readily available for commercialization. Both systems have utilized commercially available subsystems when possible to avoid needless cost and development time.

Technology Selection Considerations

Based on the INEEL demonstration, the Modified Brokk Demolition Machine with Remote Console is better suited than the baseline technology for D&D activities requiring completely remote operations. It is safer to operate, provides increased distance when operating in a radiological environment, allows continued higher productivity than manual operations, and costs nearly the same to operate. There are a few instances where the baseline technology would be preferable:

- When completely remote operations are not required and 100 ft line-of-sight provides adequate distance to protect the operator.
- When the possibility exists for falling debris to damage the Brokk camera and electronic systems or extremely dusty environments preclude the use of cameras.

APPENDIX A
REFERENCES

U.S. Department of Energy, Office of Environmental Management. 1998. Innovative Technology Summary Report: *Remote-Controlled Concrete Demolition System*. TMS ID 2100, DOE/EM-0410.

U.S. Department of Energy, Office of Environmental Management. 2000. Innovative Technology Summary Report: *Compact Remote Operator Console*. TMS ID 2180, DOE/EM-unpublished.

APPENDIX B
1999 LSDDP COST ANALYSIS DETAILS

Following is the LSDDP provided cost-analysis details for the Brokk 250 versus manual D&D activities.

Date prepared: 8/11/99

Brokk Cost Benefit by LSDDP

Operating Scenario Details
The Brokk was used with two attachments at the STF at the INEEL.

The hammer was used to break two 2–3 ft holes in the floor for creating negative air flow during asbestos removal in the sub-basement. The floor was concrete with an unexpected cast iron plate in it. It took only 15 minutes to set up the hammer and 1 hour for two operators to make the required hole. It is difficult to compare this activity with a baseline since the workers were not sure how they would have been able to make the hole through the cast-iron plate (a hand-held jackhammer and torch would not have been able to do this).

The shear was used to remove piping from the walls and drop it on the floor to clear the way for an asbestos-covered duct above the piping. A crew of 2 personnel worked for 3 days at this activity. In addition, it was used for 1 day to remove some heating, ventilation, and air conditioning ducting. During baseline operations, a crew of at least 4 people would have used hand tools to cut and lower the pipe and ducting to the floor. Scaffolding would have been needed for the job also. The job site supervisor indicated that the job went at least 10 times faster using the Brokk shear. The Brokk shear also greatly increased worker safety because personnel did not have to be in areas with falling pipes.

This cost-benefit analysis is based only on the shear deployment.

<u>Innovative Equipment Costs</u>
Assumptions:

The INEEL purchased a Brook and hammer for $118,372 ($104,750 robot and hammer + $7500 radio control + $900 cable + $3722 spares + $1500 shipping) – (per A. Smith – ASTD PM [Accelerated Site Technology Deployment, project manager])

In addition a La Bounty shear was purchased for attachment to the Brokk for $18,000 (per Tom Thiel – PM)

Add 27% G&A [General and Administrative], 5.3% Material Handling, and 4.5% Performance Indicator Factor to all base equipment costs.

Service life 15 years (N), used 1000 hours per year (based on manufacturers recommendation and D&D PM's estimates)
Assume 5.8% interest rate (I).
Vendor quoted maintenance cost of $10/hour
The overall purchase cost (P) is $ (118,372 + 18,000) * 1.27 * 1.053 * 1.045 = **$190,578**

Amortized Cost

X $/year = P ((1-(1+I) / (1-(1+I)^{N})) + I)
X= $190,578 ((1-1.058) / (1-(1.058)^{15}) + 0.058)
X= $19,367/year or ($19,367/year)/1000 hour/year = $19.37/hour
EC = $ (setup time + work time) * $19.37 + maintenance costs
EC = $(60 hours training time + 40 hours work time) * $19.37 + $10/hour (40 hours work time)
EC = **$2,337**

Innovative Assumptions:

Labor rates include all adders. Labor times gathered by ASTD project personnel from the D&D workers.
Time to set up shear – and locate it – 1.5 hours – 2 operators @ $45.50/hour = **$137**
Training – 2 operators for 60 hours @ $45.50/hour = **$5,460**
One job supervisor for 4 days for 1 hour/day for briefings ($65.44/hour) = **$262**
Two operators @ $45.50/hour for 4 days including job briefings = **$364**

Total cost = EC + training cost + setup cost + work cost
TC = $2,337 + $137 + $5460 + $262 + $364
TC = **$8,560**

Baseline Equipment Costs

Baseline is to use shears or cut-off saws (chop-saws, band saws and other hand-held tools) and scaffolding. Assume the cost of equipment use is negligible.

Baseline Assumptions

Labor rates include all adders
Set up time is minimal
Job performance is 10 times longer that of the Brokk with 4 operators (i.e., job site supervisor estimated job would take 10 * 4 days – 40 days to perform with a crew of 4 people at $45.50/hour)
Job site supervisor for 40 days at 1 hour/day for briefings @ $65.44/hour

Total Costs = EC + (4 people * 40 days * 10 hours/day * $45.50/hour) + (40 hours * $65.44/hour)
TC= 0+ $72,800 + $2618
TC = **$75,446**

Savings = $75,446 - $8,560 = **$66,886**

APPENDIX C
ACRONYMS AND ABBREVIATIONS

ASTD	Accelerated Site Technology Deployment
CRC	Compact Remote Console
D&D	deactivation and decommissioning
D&DFA	Deactivation and Decommissioning Focus Area
DOE	U.S. Department of Energy
EC	equipment cost
EM	Environmental Management
FY	Fiscal Year
G&A	General and Administrative
GUI	graphical user interface
I	interest
INEEL	Idaho National Engineering and Environmental Laboratory
ITSR	Innovative Technology Summary Report
LSDDP	Large-Scale Demonstration and Deployment Project
N	service life years
ORNL	Oak Ridge National Laboratory
OST	Office of Science and Technology
P	purchase cost
PM	Project Manager
PPE	Personal Protective Equipment
rf	radio frequency
Rbx	Robotics Crosscutting Program
STF	Security Training Facility
TC	total cost
TMS	Technology Management System
X	amortized equipment cost